Understand the value of knowledge management in a virtual asset management environment

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ABSTRACT: The research provides a practical case study to demonstrate how clients can derive value from digital information technologies and technics devoted to the management of data and information with reference to Facility Management (FM) and Asset Management (AM) activities. During the study, public assets of around 450 buildings in a municipality were analysed over a two-year time-frame. The public body acts both as client and as asset manager, facilitating the study of interactions between the two phases that is usually hindered due to the fragmentation of the subjects involved. This study demonstrates in the first instance the value of an effective information management process and secondly possible impacts and value areas of KM in building information modelling-based FM and AM. The case study presented can help clients understanding the value of information and knowledge management technologies and techniques in current asset interventions and/or in the development of future projects.

1 INTRODUCTION

The use of Building Information Modelling (BIM) in Facilities Management (FM) and Asset Management (AM) is transforming the way assets are operated and managed (Love et al. 2014). As such, BIM offers the opportunity to utilise object based intelligent models for FM and AM tasks. The inclusion of geometric and non-geometric information based on a shared semantic structure paves the way for optimised information management processes resulting in less errors, greater consistency, clarity, accuracy, and clear responsibility of authorship. BIM can be viewed as a mean for facilitating Knowledge Management (KM) activities including acquisition, extraction, storage, sharing and update of knowledge (Deshpande et al. 2014). However, research efforts on the role of KM in BIM-based FM are lacking (Charlesraj 2014) and even more serious are the efforts towards AM. With the utilisation of BIM as a central knowledge resource, there is the potential of improving information exchange and better information management within owner-operator organisations. Nevertheless, one of the problems of the Architectural, Engineering, Construction and Owner-operator (AECO) industry is the lack of learning from experiences of the use and operations of existing assets (Jensen 2009). Similarly, this deficiency has been tackled by some organisations in the industry through the development of lessons learnt databases, communities of practice, project closeout interviews and other informal techniques (Rezgui et al. 2010). The recent focus of the AECO industry on BIM and facility data brings forth the opportunity for KM in FM and AM.

The issues revealed in the diffusion of innovative technologies and techniques in FM and AM can be related to the difficulties in demonstrating the business value of information and knowledge management processes and technologies. This research provides a practical case study to individuate where clients can look for the identification of value in the use of digital technologies devoted to the management of data and information. It is recognised in case studies the more appropriate investigation to evaluate the business benefit of information systems (Bakis et al. 2006).

In first place, the research highlights issues related to a non-organised information process. Furthermore, results show how the combination of different data sources generated during operation and maintenance phases can provide useful insights for the definition of future projects requirements. Thus, showing the relation between the characteristic of a building and/or of its components and the maintenance costs. Starting from the optimisation of information management processes, the study envisages the use of facility information for knowledge generation and its applicability in decision-making processes. This study demonstrates in the first instance the value of an effective information management process and secondly possible impacts and value areas of KM in BIM-based FM and AM. The case study presented can help clients in understanding the value of information and knowledge management technologies and techniques in current asset interventions and/or in the development of future projects.

The rest of the paper is organised as follows. Section 2 introduces the background including the identification of the value embedded in information. Section 3 presents the proposed case study including the methods used for its development. Section 4 and 5 contain a discussion about the obtained results and conclusions.

2 BACKGROUND

BIM on its own can offer a useful and personalised graphical visualisation of the contents of a database. However, even if representation of the data can provide useful information to individual users it cannot be seen as knowledge transfer. Knowledge needs the identification of patterns behind the information and the human action to gain power in the process (Kamaruzzaman et al. 2016). Information needs to be merged, combined and analysed including domain specific a-priori knowledge to find patterns and extract knowledge (Fayyad et al. 1996). Nevertheless, measuring the value of intangible assets like KM is difficult (Kaplan & Norton 2004) and an incorrect perception can undermine its effective introduction. Hence, a clear vision on the value of information and the possible implication of KM in AM is required.

2.1 *Knowledge Management (KM) in Asset Management (AM)*

KM is defined as any process that enhances organisational learning and performance through the process of creating, acquiring, capturing, sharing and using knowledge (Scarborough et al. 1999). Similarly, Jennex (2005) defines KM as the process of utilising organisational experience as a knowledge base and the selective application of those experiences to current and future decisions with the sole aim of improving organisational effectiveness. There are several benefits that can be gained from the knowledge accumulated in AM activities. This is because, an organisation's competitive advantage depends on what it knows, how it uses that knowledge, and how fast it can learn something new (Charlesraj 2014). Asset managers may require the integration of various types of information such as work orders and maintenance records across different parts of the business for decisions on asset interventions in order to apply knowledge-based decisions (Motawa & Almarshad 2013).

On the other hand, Rainer & Turban (2009) define knowledge as *'data and/or information that have been organized and processed to convey understanding, experience, accumulated learning and expertise as they apply to a current problem'*. Similarly, Alavi & Leidner (2001) suggest that knowledge becomes information when it can be interpreted by individuals. Furthermore, they go on to describe that knowledge can become information if it can be expressed in words, graphic or other representations.

2.2 *Value of Information*

Senn (1990) defines information as data presented in a form that is meaningful to the recipient. Therefore, information management processes and techniques have become important aspects of AM. Asset managers utilise hardware and software as mechanisms to create and maintain information within their organisation. These technologies and processes are means of delivering information, whilst information is the asset that can be used to gain strategic advantage by the organisation (Moody & Walsh 1999).

In trying to identify the value of information, Moody & Walsh (1999) proposed seven laws of information, these are:

- information is (infinitely) shareable; the value of information increases with use
- information is perishable
- the value of information increases with accuracy
- the value of information increases when combined with other information
- more is not necessarily better
- information is not depletable.

Similarly Burk & Horton (1998) identified nine similarities between information and assets, these are:

- information is acquired at a definite measurable cost
- information possesses a definite value, which may be quantified and treated as an accountable asset
- information consumption can be quantified
- cost accounting techniques can be applied to improve the control of costs associated to information
- information has identifiable and measurable characteristics
- information has a clear life-cycle
- information may be processed and refined
- substitutes for any specified item or collection of information is available and may be quantified as more or less expensive

- choices are available to management in making trade-offs between different grades, types and prices for information.

Miller (1996) suggests that in order to information to be valuable it has to have these qualities, they are: relevance, accuracy, timeliness, completeness, coherence, format, accessibility, compatibility, security, and validity. On the other hand, there is the view of information from two perspectives of value, which are: philosophical and practical (Repo 1986, Repo 1989) value. These two perspectives can be used to highlight that value depends on the users' perception. Engelsman (2007) reviewed six approaches to valuing information in the normative literature, they are: valuation in risk perspective (Poore 2000); Historical cost valuation (Moody & Walsh 1999); usage over time valuation (Chen 2005); utility value of information (Glazer 1993); and valuation of knowledge assets (Wilkinns et al. 1997). Furthermore, Engelsman (2007), proposed a four-step framework to valuing information, they are; identify the information asset; determine the audience for valuation; determine context and value information.

Asset managers have tried to create systems that enable them to utilise their knowledge-base through the delivery of quality data but end up having results that are missing required information or embedded with significant amounts of meaningless data (Brous et al. 2015). The problem for organisations is not the production of data but capturing, interpreting and managing them for future decisions. Information is at its lowest value when the organisation does not know it exists. Unused information can be termed as a liability for asset owners because they extracts no value from it and the organisation continuously incurs cost for storage and maintenance (Moody & Walsh 1999). The value of data increases when an organisation is able to integrate its systems and collect data from various aspects of its business in order to make simulations and analysis that will aid decision making and improve the execution of future processes.

Despite gaining recognition as an asset in its own right, information has so far resisted quantitative measurement because it has no real value until it is utilised (Moody & Walsh 1999). As a result, there is no consensus on how to measure the value of information.

2.3 *Asset Intervention*

Asset intervention which is also referred to as building maintenance *'is the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function'* (BS 3811 1984). Motawa & Almarshad (2013) classified maintenance into two main categories, preventive and corrective. Similarly, BS 3811 (1984) divides maintenance into two: planned and unplanned maintenance. It further presented other classifications of planned maintenance which are preventive, corrective, condition-based and scheduled maintenance. Furthermore, Chanter & Swallow (2007) distinguish maintenance activities into planned and unplanned maintenance. They also described maintenance which is based on operational decisions as shown in Figure 1.

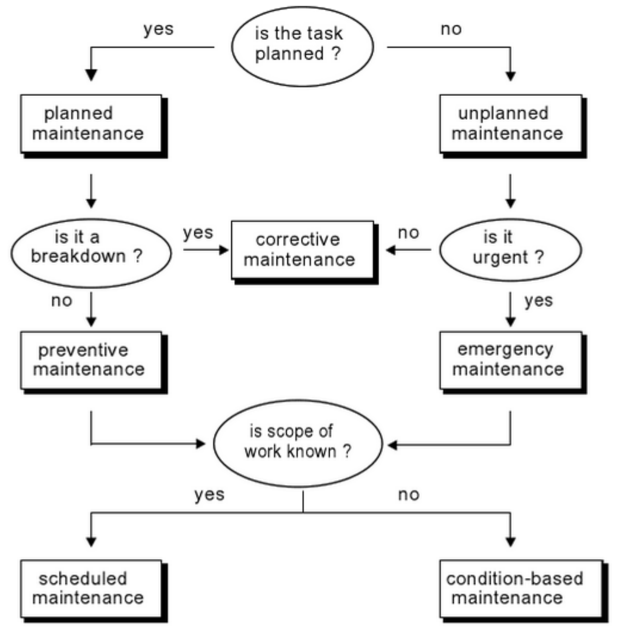

Figure 1. Types of maintenance (Chanter and Swallow, 2007)

2.3.1 *Planned Maintenance (PM)*

PM involves maintenance activities carried out by an organisation according to a predetermined plan (BS 3811 1984). This may also refer to preventive, scheduled or condition-based maintenance (Chanter & Swallow 2007). These activities are planned to prevent failure and to extend the service life of assets. The technique of PM was developed to address the traditional maintenance approach of only fixing broken assets (Munchiri et al. 2017).

Asset owners benefit from this approach because PM extends asset life, reduces down-time, improves safety, and reduces the need for premature capital investments.

2.3.2 *Unplanned Maintenance*

Unplanned maintenance involves ad-hoc maintenance activities carried out by an organisation with no predetermined plan (BS 3811 1984). This is a reactive strategy where assets are only fixed when they are broken (Munchiri et al. 2017). This asset intervention strategy is most suitable for inexpensive elements and those that are easy to replace.

3 CASE STUDY

3.1 *Methods*

During the study, public assets of around 450 buildings has been analysed in a municipality over a two-year time frame. The public body acts both as client and asset manager facilitating the study of possible interactions between the two phases that is usually hindered due to the fragmentation of the subjects involved. These aspects facilitated the analysis of possible repercussions of the proposed study on the definition of future requirements for new projects and/or renovation activities.

Archival analysis of facility information based on asset interventions were conducted for the purpose of this study. A first step of data cleaning based on data quality techniques (Hernández & Stolfo 1998) has been developed. In particular, facility information was non-homogeneous and distributed on several distinct sources (files and/or databases). Hence, during the data cleaning activities, the information has been aggregated and uniformed to allow future analysis. Moreover, a high number of empty cells have been registered with consequent problems related to the correct interpretation of the missing information (Zaniolo 1984).

Starting from the cleaned data, two main kinds of analysis have been developed. On the one hand, the information has been represented in meaningful graphical form to provide a better comprehension of possible relations. This first step can be interpreted as an improvement in the information management process with the consequent increase of the information availability and accessibility.

On the other hand, the information has been analysed using statistical techniques such as linear regression to identify unknown patterns behind the data and thus provide knowledge to the facility manger. This second step of analysis can be viewed as a further one in comparison to the information management because the effective use of the information provides unseen patterns moving the focus from information to knowledge generation.

While information visualisation (first level) is mainly devoted to the analysis of the entire dataset aggregating the information, the application of linear regression analysis (second level) needs the study of data related to single buildings. Since the data cleaning activity highlighted the impossibility to define precise data on all the single buildings, only a sub-set of the asset has been included in the second level analysis. To avoid possible deviations in the results, the areas characterised by a high concentration of historical buildings have been omitted.

Figure 2 represents the research path followed in the development of the proposed case study. The statistical analysis proposed takes into account the value of data integration that will be discussed in detail in section 4.

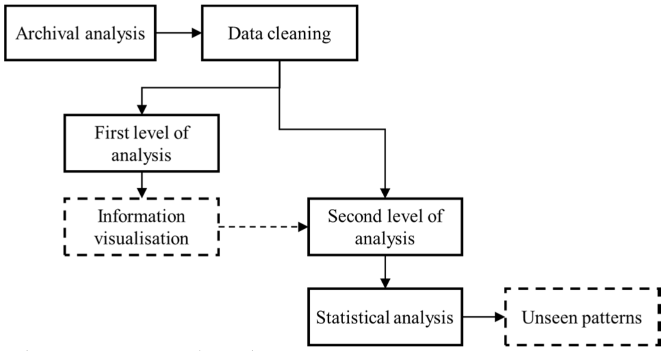

Figure 2. Research path

3.2 *First level of analysis: information management*

As described in section 3.1, the first level of analysis is focused on the representation of the data contained in the cleaned data set. This first phase can be used to demonstrate the potential benefit of better information management processes that can facilitate the availability, accessibility and usability of data through information visualisation means. In particular, three main areas have been analysed, namely total maintenance costs associated to specific work types, frequency of maintenance intervention associated to specific work types and the order of works characteristics in terms of work optimisation.

In this section, the main results associated to the proposed case study in terms of data visualisation are described, while a detailed analysis with reference to value association will be proposed in section 4.

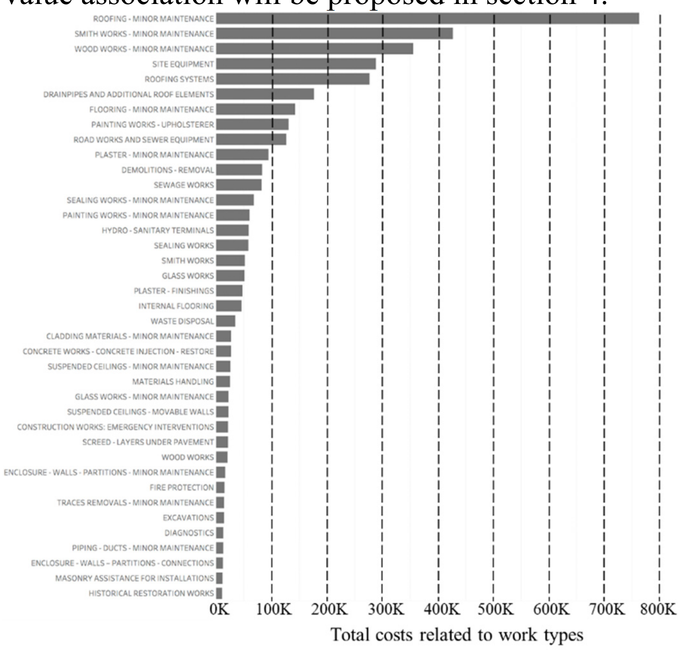

Figure 3. Total costs (in thousands of euros) related to work types

Figure 3 shows the total cost of maintenance on the entire asset divided according to the work types registered in the selected time span. This visualisation can help in identifying the main areas of costs in maintenance processes guiding the facility manager in monitoring activities. For example, in the proposed visualisation it is clear that there is great impact of minor maintenance on roofs, followed by minor maintenance of smith works and wood works.

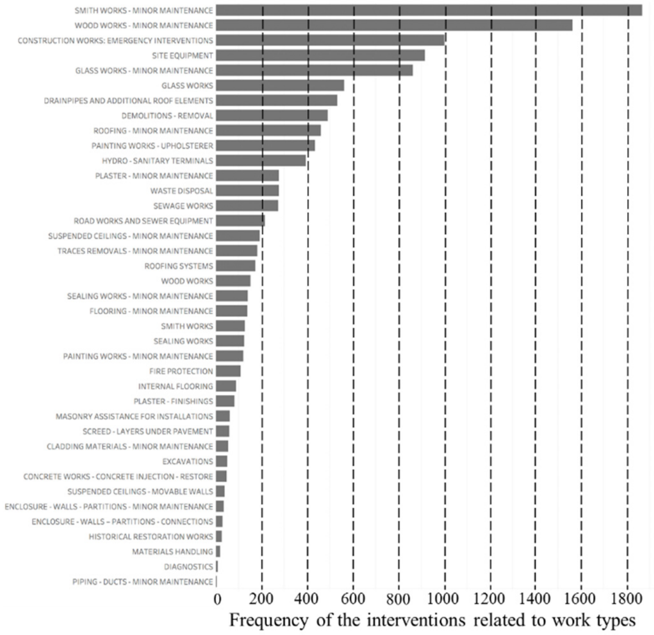

Figure 4. Frequency of the intervention related to work types

Figure 4 shows the frequency of maintenance intervention in relation to the same work types analysed in Figure 3. Following the same principle presented for Figure 3, the identification of the work types that requires a high frequency in maintenance intervention can guide the facility manager in identifying possible issues and activate corrective actions. In this case, minor maintenance of smith works and wood works have the highest impact.

Combining the two analyses can help identifying possible issues related to minor maintenance of smith works and wood works due to their high impact in terms of both costs and frequency.

The third part of the analysis included in the first level is focused on the study of the orders of works. Work orders identify the means through which the facility manager requires maintenance works to the company in charge. In particular, 584 orders have been included in the analysis studying both the number of works comprised in one order and the total cost of each order. Starting from the global representation of the analysis that reports a maximum cost per order equal to 18000 euros and a maximum number of works in one order equal to 18, Figure 5 shows a focus of the graph in the area possible issues can be identified. In fact, the definition of work orders with a small cost and a small number of associated works can reveal possible inefficiencies helping the facility manager in the identification of possible corrective actions in the process.

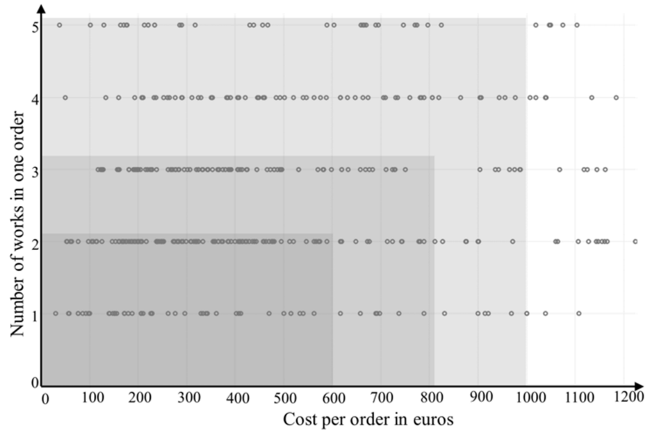

Figure 5. Order of works during the year and related cost

Starting from this principle, in Figure 5 3 main clusters have been identified to better understand the characteristics of the maintenance activities. The first cluster (dark grey area) identifies all the work orders with a total cost minor or equal to 600 euros and with a total number of works minor or equal to two. The second cluster (middle grey area) identifies all the work orders with a total cost minor or equal to 800 euros and with a total number of works minor or equal to 3. The third cluster (light grey area) identifies all the work orders with a total cost minor or equal to 1000 euros and with a total number of works minor or equal to 5. The number of work orders included in each cluster are following listed (percentage impact on the total in brackets):

- First cluster 173 (29,72%)
- Second cluster 284 (48,63%)
- Third cluster 403 (69,01%)

The high number of work orders included in these clusters highlights the prevalent presence of unplanned maintenance. The detailed study of the work types included in the work orders in the different clusters can help the facility manager in the definition of possible action devoted to the optimisation of future interventions.

The results proposed in this section demonstrated how the integration of data visualisation means in information management processes can provide highly accessible information with a consequent increase in the information value as discussed in section 4.

3.3 *Second level of analysis: knowledge creation*

In an organisation, the budget devoted to maintenance activities on buildings can be defined on annual basis according to relevant parameters related to the buildings such as the surface or the number of daily users. In the proposed case study, all the buildings included in the statistical analysis were schools. In school buildings parameters can be the number of students or the dimension of the school in square or cubic meters. However, the definition of a maintenance cost per year per square meter is difficult and do not consider the characteristics of the school, bringing to possible over or underestimation of the costs.

Starting from the data organised and cleaned, it is possible to identify relations among parameters of the school data to obtain better forecasts for future maintenance. An example is the use of a linear regression model to identify unknown relations between the characteristics of the schools and their maintenance costs.

Due to the short time frame considered in this study, i.e. two year' time frame, some results yielded insignificant relationships, for example the relation between year of construction of the building and costs. Nevertheless, the number of floors of the schools shows a significant relation with the costs of maintenance. Table 1 proposes the results of the analysis where the constant term represent the cost of maintenance per year per cubic meter.

Table 1. Results of the linear regression model.

Terms of the model	**Results**
Constant Term	3.057 (0.00)*
Number of floors	- 0.746 (0.00)*
Adjusted R^2	0.3606
Joint F-test	54.01
Number of observations	95

*Significant test reported in brackets

Results show how the number of floors is indirectly related to the maintenance cost. In particular, starting from a constant cost of 3.057 euros per cubic meter, a school with one floor would require 2.311 euros per cubic meter per year, while a school with two floors would require 1.565 euros per cubic meter per year.

These insights can be also used for the definition of requirements for future schools. For example, the proposed analysis highlights how the number of floors in a school diminishes the costs of maintenance. Hence, future projects for new schools can require buildings with more floors to optimise the maintenance costs.

4 DISCUSSION

The results obtained through the case study proposed in section 3, can be used to identify and clarify the value of information and knowledge in AM and FM practices supported by digital information technologies and techniques.

Starting from the data cleaning activities, it can be noted that several buildings have been removed from the analysis due to a high number of unknown information and/or not coherent information. Furthermore, among the buildings maintained in the analysis, several empty cells have been individuated. Empty cells can represent a not trivial issue due to the impossibility in defining the reasons behind the empty value. Consequently, the related information is lost. Furthermore, with reference to geometrical information, the presence of documents that contain the information in a not computable format (e.g. 2D drawings in pdf format) reduces the number of information that can be included in the analysis. For example, the analysis proposed in section 2.3, shows the possibility to provide useful information to the administration. However, due to the limited number of geometrical information available in machine readable format, the analysis is bounded to a poor number of parameters. In the future, the use of digital models related to the asset will provide precise geometrical information that can be used in the improvement of the proposed framework to guarantee better performance and more precise information. Hence, BIM can be viewed as a facilitator for the development of data analytics application on buildings data, thanks to the increased availability of machine readable information both in terms of geometrical and non-geometrical data.

These first considerations highlight a valuable point in the identification of the value behind the introduction of digital based information management processes. On the one hand, it can be noted a direct improvement in the accessibility and usability of the data with the consequent reduction in the related time and costs. On the other hand, the increased availability of the data paves the way for the development of statistical applications as proposed in section 3.3.

Relating these evidences with the parameters connected to information value presented in section 2.2 it can be stated that the case study demonstrated a value increase improving the possible uses of information and the quality and consequently the accuracy of information.

The availability of structured data related to different aspects of the maintenance process (e.g. costs, building characteristics and maintenance activities) can be used to generate new knowledge as proposed in section 3.3. This aspect acts directly on the value of information associated to the combination of sources. However, the main benefit can be related to the increased comprehension of the dynamics behind the maintenance process thanks to the extraction of unseen knowledge from an extended data set. In fact, the introduction of information management processes can produce defined benefits as discussed in the previous paragraphs. However, these benefits do not express the complete potential behind the increased information availability, that is the creation of new knowledge that can be used to change and improve the entire maintenance process.

This has been already discussed as the analysis proposed in the second level can produce unseen knowledge. However, it can be noted in the literature a discrepancy between the represented knowledge and the knowledge perceived by the user according to his or her past knowledge. In this study the passage between the knowledge creation to the knowledge conversion and integration in human mind is not addressed and can be identified as a future line of research.

Finally, the example proposed in section 3.3 demonstrates how the possible impacts derived from the use of information is not limited to the maintenance process but can be extended to other activities such as the design of new buildings. The information can be used to identify possible relation between maintenance costs and building characteristics or to study the characteristics of elements that demonstrated low performances during the building use. Hence, this information can constitute the basis for the development of information-based project requirements towards the definition of computable project requirements. This last area is gaining increasing interest in the scientific field and it represents a critical point for the introduction of BIM in structured clients such as public administrations.

5 CONCLUSION

The understanding of the value (in terms of possible positive effects) of the use of BIM or in general digital techniques and technologies for better information and knowledge management is a critical issue and can hinder the adoption of BIM in FM and AM. This paper presents a practical case study that can contribute in the understanding of the value of effective information and knowledge management in FM and AM to push the industry and the research in the exploration of new uses for data and information. In particular, through the study of the data produced during maintenance activities on public assets of 450 buildings in a two year' time span, has presented possible applications that can help in the identification of the positive effects derived from a structured data organisation and an effective use of this data. The results obtained in the case study, have been compared to key value indicators associated to information value to highlight the impacts of digital technologies and techniques in the maintenance process. Furthermore, the paper propose a perspective interpretation that looks on possible future applications that the increasing production of machine-readable data can produce. In particular, the introduction of statistical means and more in general of data analytics applications on maintenance. This has demonstrated the possibility to provide useful information and consequently produce important change in actual processes in the logic of learning from the past through the data.

The study highlights several issues with reference to the availability and accessibility of the data. These issues hindered the extended exploration of possible data analytics applications. Hence, future case studies can explore the integration of digital models and/or of computable information related to the characteristics of buildings and of their elements (e.g. geometry and main features) to integrate the proposed analysis with further evidences that can extend the presented uses.

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